DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20034

BIAS BUOY MEASUREMENT AND DEPTH CONTROL INSTRUMENTATION

by

Robert J. Singleton

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SHIP PERFORMANCE DEPARTMENT
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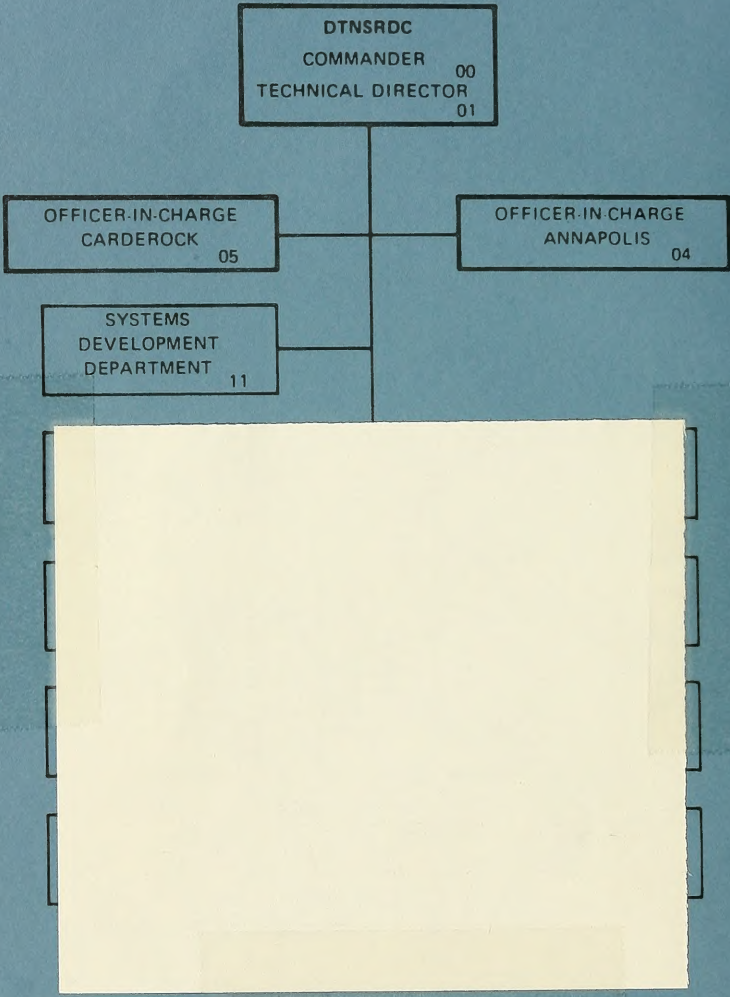

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An electronic system has been developed to measure and record certain hydrodynamic characteristics of a towed buoy to be the antenna platform for a submarine communications system designated BIAS (Buoy Integrated Antenna Submarine). The system is for use during submarine development-assist tow trials. The quantities measured are buoy pitch, horizontal stabilizer angle, depth (shallow and deep), cable tension at the submarine, cable scope (fine and coarse), submarine depth, and speed.

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A second electronic measurement system was developed to measure and indicate the required hydrodynamic characteristics of the buoy necessary for operation of the system during submarine patrols. The quantities measured are displayed as meter readouts and include buoy depth (shallow and deep), cable tension at the submarine, and cable scope (fine and coarse).

TABLE OF CONTENTS

LIST OF FIGURES

Page

ABSTRACT

An electronic system has been developed to measure and record certain hydrodynamic characteristics of a towed buoy to be the antenna platform for a submarine communications system designated BIAS (Buoy Integrated Antenna Submarine). The system is for use during submarine development-assist tow trials. The quantities measured are buoy pitch, horizontal stabilizer angle, depth (shallow and deep), cable tension at the submarine, cable scope (fine and coarse), submarine depth, and speed.

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ADMINISTRATIVE INFORMATION

The work described in this report was performed for the Naval Ship Engineering Center (NAVSEC) as part of Subproject S3203, David W. Taylor Naval Ship Research and Development Center (DTNSRDC) Work Unit 1-1548-402.

INTRODUCTION

At the request of NAVSEC, DTNSRDC undertook a program to develop a towed buoy and cable system to act as an antenna platform for a communications system for use on ASW submarines. The system is designated BIAS (Buoy Integrated Antenna Submarine).

As part of the BIAS buoy development program, two electronic measurement systems and an automatic buoy depth control system were designed and fabricated. One measurement system was designed to accurately measure buoy and towcable parameters for validation of performance predictions at sea. An automatic depth control system was designed to control the buoy for two ranges of depth-keeping: (1) near-surface following and (2) the sub-surface depth required for very low frequency (VLF) reception. A second measurement system was manufactured for permanent placement aboard the submarine to be used for operation of the BIAS system while deployed at sea.

The approach taken by the David W. Taylor Naval Ship Research and Development Center was to select the necessary sensors, to design the electronic systems for data transmission and recording (or indicating), to design an automatic buoy depth-keeping servo-control system, and to package the resulting components for evaluation experiments in the BIAS buoy system.

This report describes the Evaluation Measurement System and associated depth-keeping servo system, briefly explains the principles of operation and describes the hardware. The report also includes a description of the measurement system permanently installed aboard the submarine required for BIAS buoy operation.

GENERAL CONSIDERATIONS

One of the requirements for development of the BIAS buoy communication system was the design and fabrication of an instrumentation system to measure certain buoy and tow-cable parameters while under tow. Measurement of these parameters would serve four purposes: (1) to provide basic quantitative hydromechanic evaluation of buoy design during experiments in the towing basins of the Center and at sea, (2) to confirm predicted towcable configurations at sea, (3) to provide the submarine operating crew with the necessary data for buoy-positioning winch operation, and (4) to provide warning of malfunctions in order that corrective action may be taken to assure submarine safety.

In addition to the above requirement, an automatic buoy depth-keeping system was highly desirable. This system would operate in two automatic modes: (1) to cause the buoy to follow 4 feet below the water surface (a requirement for high-frequency radio transmission and reception) and (2) to cause the buoy to operate at a nominal 20 feet deep (for VLF reception only).

The hydromechanics evaluation of a cable-buoy system requires the measurement of the nine parameters listed in Table 1 to provide the data necessary for validation of the steady-state cable configurations. The general towing configuration and the location of the various sensors are depicted in Figure 1. The signals from the buoy sensors are telemetered down one conductor of the towcable for recording at the data center. A remotely controlled and automatic sequencing switch network is incorporated within the buoy instrument housing to zero reference and electrically calibrate the sensors which may be used to eliminate measurement errors due to long-term sensitivity and zero shifts of the data transmitting and recording electronics. The sensors at the submarine end of the towcable are direct-wired to the data center for recording.

PRINCIPLES OF OPERATION

The following discussion deals with the general operating principles of the Buoy Evaluation Measurement System (which includes an Automatic Buoy Depth-Keeping System) and a Buoy Operational Measurement System for use by the submarine crew while on patrol.

TABLE 1 – MEASURED QUANTITIES AND SYSTEM SENSORS

MEASUREMENT	PHYSICAL TYPE SENSOR	ELECTRICAL TYPE SENSOR	RANGE	SENSOR ACCURACY	MANUFACTURER	MODEL NUMBER
BUOY PITCH	VISCOUS-DAMPED PENDULUM	2000 - OHM POTENTIOMETER	± 20 deg	±0.2 deg	EDCLIFF INSTRUMENTS	5-510
BUOY SHALLOW DEPTH	PRESSURE GAGE	2000 - OHM POTENTIOMETER	0-50 feet	±0.5 feet	SPARTON SOUTHWEST INC.	401 - W-5-20
BUOY DEEP DEPTH	PRESSURE GAGE	2000 - OHM POTENTIOMETER	0-1000 feet	±10 feet	SPARTON SOUTHWEST INC.	890.47 W-100-20
BUOY HORIZ. STABILIZER ANGLE	SINGLE-TURN POTENTIOMETER	2000 - OHM POTENTIOMETER	±15 deg	± 0.15 deg	COMPUTER INSTRUMENT CORP.	105
SUBMARINE DEPTH	PRESSURE GAGE	2000 - OHM POTENTIOMETER	0-1000 feet	±10 feet	SPARTON SOUTHWEST INC.	890.47 - W-100-20
CABLE TENSION	STRAIN GAGE FLEXURE	700 - OHM FOUR-ARM BRIDGE	0-5000 lbs.	±250 lbs.	OAK RIDGE	2161
CABLE FINE SCOPE	SINGLE-TURN POTENTIOMETER	300 - OHM POTENTIOMETER	0-75 feet	±1 foot	BECKMAN HELIPOT	5711
CABLE COARSE SCOPE	25 TURN POTENTIOMETER	300 - OHM POTENTIOMETER	0-1500 feet	±10 feet	BECKMAN HELIPOT	DR300 L-5
SUBMARINE SPEED	ELECTROMAGNETIC LOG		CLASSIFIED		SHIPS EQUIPMENT	

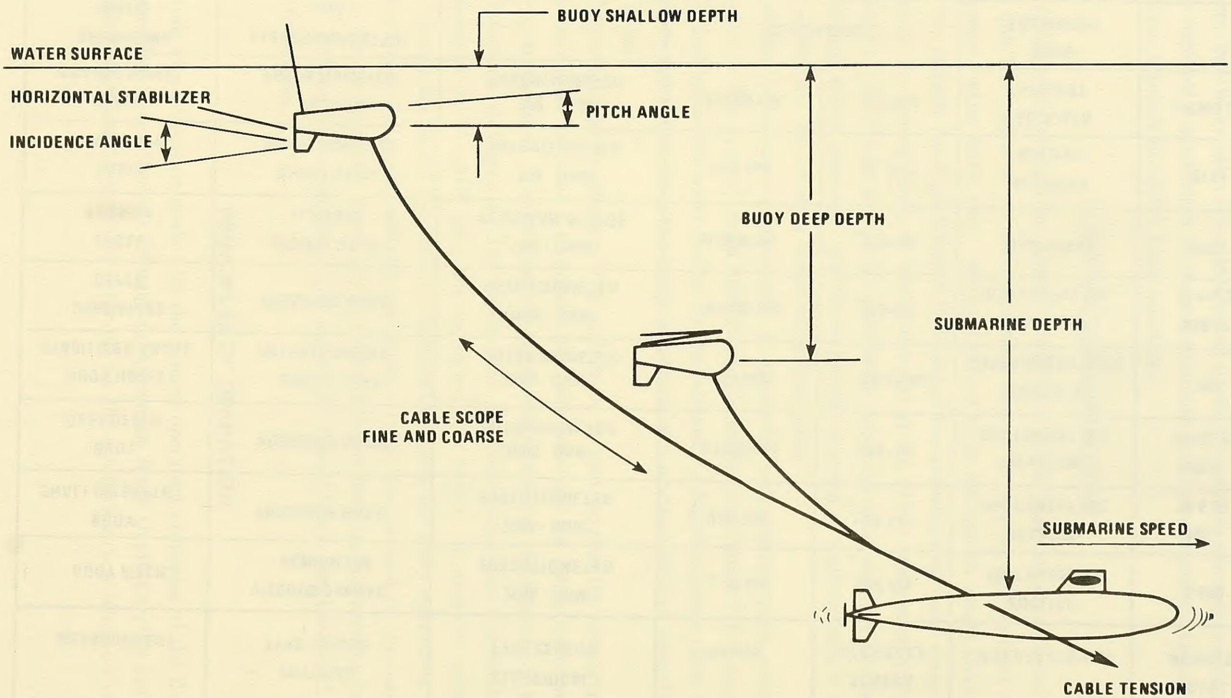

Figure 1 – General Towing Configurations with Antenna Folded or Erect

BUOY EVALUATION MEASUREMENT SYSTEM

This system is designed for accurate measurement of buoy and towcable parameters while the buoy system is towed for evaluation purposes. A simplified block diagram of this system and a partial schematic of buoy instrumentation (showing only one typical sensor channel) are presented in Figures 2 and 3, and a detailed schematic is shown on DTNSRDC Drawing C-432-2. Within the buoy there are four potentiometer-type sensors, each of which generates a 0- to 5-volt d-c output as a function of the physical parameter being sensed. These parameters include buoy pitch, buoy horizontal stabilizer angle, buoy deep depth, and buoy shallow depth. In addition, there are two leak detectors which generate electrical pulses only if leakage occurs within the watertight compartments. The leak-detector outputs are coupled with the pitch and deep depth signals and appear as momentary blips atop the recorded parameters. In conjunction with each sensor there is an electrical calibration network with three voltage taps. A rotary-solenoid switch is used to make electrical contact with these taps and the sensor output. To complete a calibration sequence, the stepping switch is rotated through four switch positions entitled: Zero Check, Cal 1, Cal 2, and Data. the Zero Check position corresponds to a physical-sensor zero; Cal 1 represents a discrete physical-sensor displacement; Cal 2 represents a second but different displacement than Cal 1; and finally the Data position corresponds to the direct output of the sensor.

The rotary solenoid is energized and the switches are automatically sequenced through the four positions by a silicone-controlled rectifier and an oscillator network. The switching sequence is initiated by depressing a pushbutton switch in the data center, which causes an electrical impulse to travel up the towcable to the calibration sequencing network.

Commercially available voltage-controlled oscillators (VCO's) of the Inter-Range Instrumentation Group (IRIG) frequency assignments are used in this system for combining the four sensor outputs into one composite signal for single-conductor transmission down the towcable. The d-c voltage output (or cal signal) of each sensor is connected to a VCO. Each VCO converts the d-c input signal to an a-c frequency wherein the frequency deviation from a center frequency is proportional to the variation of the d-c voltage input. The center frequency of each VCO is different from the next such that if all the VCO frequency outputs are mixed there will be no overlapping or interfering frequencies. The four VCO outputs are mixed and input to a low impedance line driver for transmission down the towcable.

Within the data center the telemetry signal is unscrambled by a four channel frequency modulated (FM) discriminator. This instrument sorts out the four frequency bands and converts each frequency band to a d-c voltage proportional to the sensor output. The four discriminator outputs then are connected to the input of a multichannel strip-chart recorder which produces a time-history trace of each of the physical inputs to the buoy sensors.

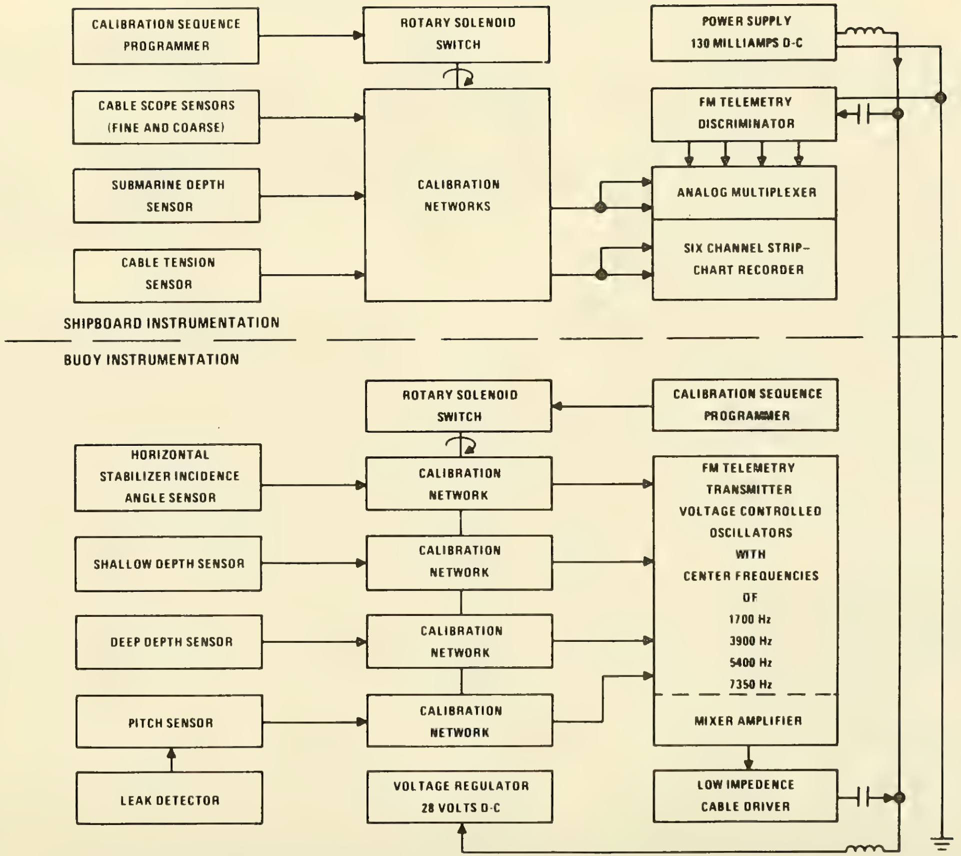

Figure 2 — Block Diagram of the Buoy Evaluation Measurement System

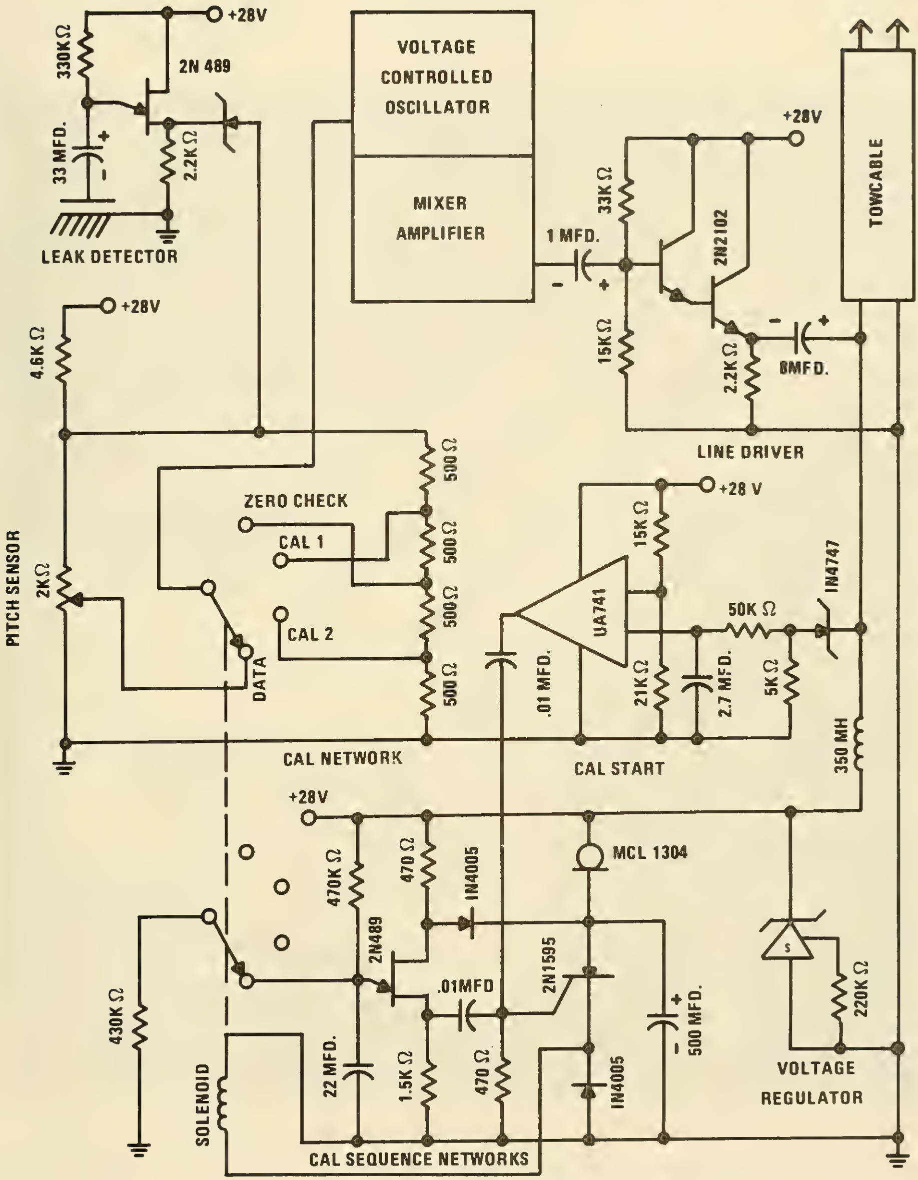

Figure 3 – Partial Schematic of Buoy Instrumentation

The electronics of the buoy are energized by a d-c power supply (located in the data center) via the same conductor used for data transmission. The a-c composite datum signal is decoupled from the d-c supply by an inductive-capacitive network at each end of the towcable.

During preliminary sea trials it was noted that the telemetry signal was interfering with VLF reception. As a consequence, a modification was made to the instrument system which permits shutdown of the telemetry portion but still allows buoy depth datum transmission to the data center. Telemetry cutoff is accomplished by remote control of a relay in the buoy which interrupts the supply voltage to the VCO's. The two depth-sensor d-c outputs are summed and the summed signal is converted to a d-c current signal for transmission to the data center on a separate lead within the towcable.

To complete the buoy-towcable measurement requirements there are four measurements made from sensors mounted in the buoy nest area aboard the submarine. These parameters are cable tension, submarine depth, fine cable scope, and coarse cable scope.

The cable tension sensor, a four-arm strain gage bridge, is directly wired to the data center via four conductors. The remaining sensors are potentiometer-type gages which also are direct wired to the data center. Each sensor is interwired into a calibration network similar to that described previously. A multiple-rotary-solenoid switch and sequencing network, identical to the one in the buoy, is operated from the Cal-Start pushbutton on the front panel of the data center control unit.

The four direct-coupled sensor outputs (or cal signals) are input to the strip-chart recorder for time-history readouts. A submarine speed signal is provided by the ship's electromagnetic log and is recorded with the above parameters.

As may be noted there are nine parameters to be measured. Because of the limited space in the submarine, a small, six-channel strip-chart recorder was used. Therefore, a three-channel multiplexer or time-sharing instrument was fabricated at the Center to allow three groups of parameter pairs to be recorded on three recorder channels. The three paired parameters are: fine cable scope and coarse cable scope, deep buoy depth and shallow buoy depth, and buoy pitch and horizontal stabilizer angle. Submarine speed, submarine depth, and towcable tension are recorded separately on the remaining three recorder channels.

AUTOMATIC DEPTH-KEEPING SYSTEM

To determine the feasibility of automatic buoy depth control, a servo system to automatically control buoy depth via actuation of the buoy horizontal stabilizer was designed and manufactured as part of the BIAS buoy program. A photograph of the BIAS buoy is presented in Figure 4, which shows the arrangement of the tail assembly which consists of vertical fins and a horizontal stabilizer.

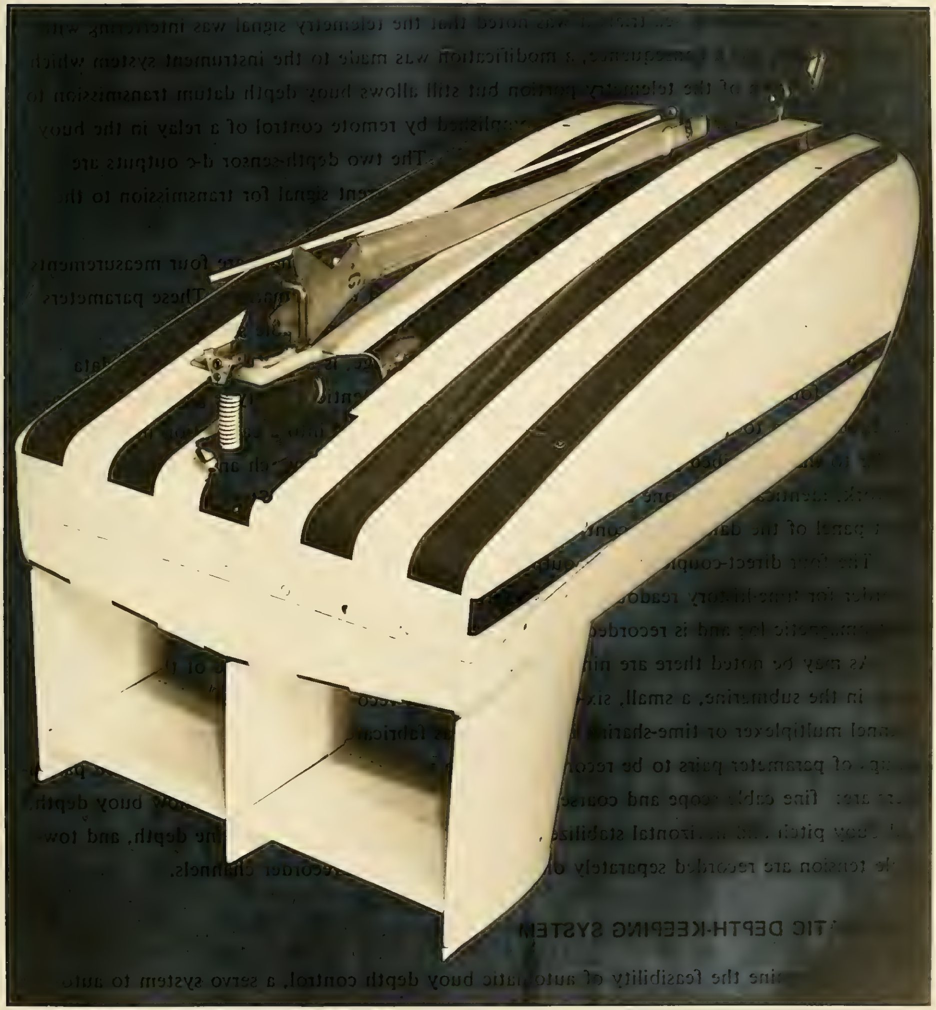

Figure 4 – The BIAS Buoy

A simplified schematic of the automatic depth-keeping system is shown in Figure 5 and a detailed schematic is provided in DTNSRDC Drawing C-398-4. A servo motor, mounted in the buoy center vertical fin, is capable of producing 3-foot-pounds of torque to drive or position the horizontal stabilizer attack angle. The servo motor is remotely controlled from the data center via two leads in the towcable. The servo motor, and hence the stabilizer, can be remotely controlled in four operational modes: three modes utilize a servo amplifier and one mode uses a double-pole, triple-throw switch directly coupled to a power supply.

The various modes of horizontal stabilizer control were provided to maximize operational flexibility during evaluation experiments of the BIAS buoy system. The principles of operation of each mode are discussed in order that the final depth-keeping mode of operation might be more easily perceived.

The first mode allows for manual positioning of the stabilizer to any angle within the allowable plus or minus 15-degree range. The Automatic Manual Selector Switch is set to the MANUAL position. The Manual Control Direction Switch is a three position spring-return-to-center switch; the center position is OFF (no power to the servo motor). When this switch is held to one side, the stabilizer rotates in one direction; if the switch is held to the other side of center, the stabilizer rotates in the opposite direction. The position of the stabilizer is determined from observing the recorded angle on the strip-chart recorder of the measurement system.

The second mode, using the servo amplifier, allows for potentiometer control of the stabilizer position wherein the angle of the stabilizer is preset to any desired angle by discrete positioning of the Control Potentiometer. The Automatic Manual Selector Switch is placed in the AUTOMATIC position and the gain adjustments of the servo amplifier are adjusted to zero except for the stabilizer position input which is adjusted for proper gain. The telemetered horizontal stabilizer-angle signal from the discriminator is summed with the d-c output or bias signal of a control potentiometer energized from a fixed voltage supply of plus and minus 15-volts (see Figure 5). When the sum of the stabilizer-angle signal and the Control Potentiometer signal are zero (referenced to ground), the servo motor is stopped. If the Control Potentiometer position is manually changed, the summing voltage will change proportionately from ground level; the servo amplifier will generate an output signal to rotate the servo motor and change the stabilizer angle. The stabilizer will rotate until the stabilizer position sensor output nulls the Control Potentiometer output and the servo motor will stop, thus accomplishing the desired new stabilizer-angle setting.

A third mode allows for automatic control of buoy pitch where the stabilizer angle automatically changes to hold a predetermined buoy pitch. The Pitch Control switch is placed in position 2 and the gain adjustment of the pitch/pitch-rate channel of the servo amplifier input is adjusted for proper gain. The servo amplifier now receives the summed

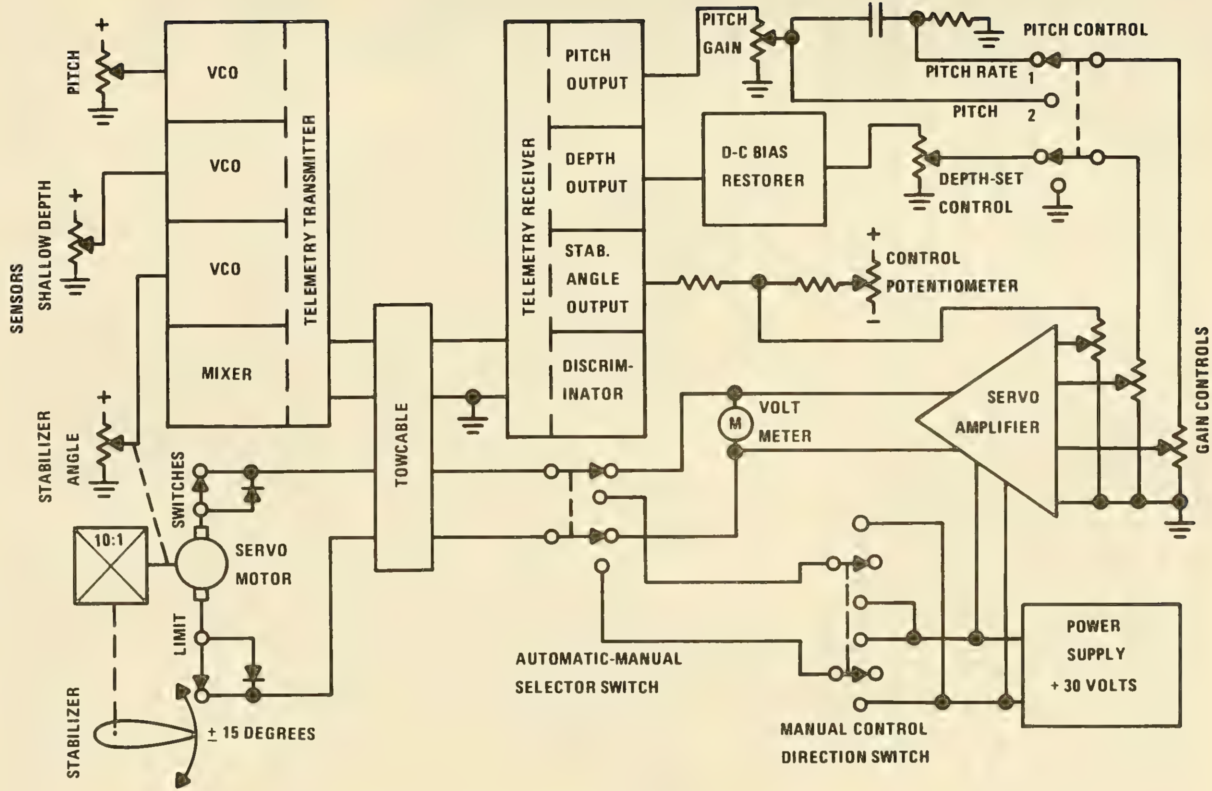

Figure 5 – Simplified Schematic of the Automatic Depth-Keeping System

outputs of the potentiometer control signal and the two telemetered buoy signals of pitch and stabilizer angle.

As in Mode 2, the stabilizer angle will remain fixed (servo motor stopped) if the sum of the three inputs to the servo amplifier equals zero (referenced to ground). For example, if the buoy pitch is steady, the stabilizer angle will remain essentially constant. If the buoy pitch tends to nose down, the telemetered buoy-pitch signal will change and the summed input signals will change from zero. The servo amplifier will energize the servo motor which will cause the stabilizer incidence angle to change to a leading-edge-down position. The new stabilizer incidence angle will cause the buoy pitch to change to a nose-up position. The stabilizer will continue to rotate until the buoy pitch equals the desired pitch at which time the servo motor will stop and the stabilizer will be reset to a new incidence angle to maintain the proper pitch. The buoy pitch angle can be arbitrarily changed or reset by manipulation of the Control Potentiometer.

The fourth mode of operation, the BIAS buoy automatic depth-keeping mode, was basically designed for two ranges of depth: (1) a nominal 20-feet below the surface, and (2) a nominal 4-feet below the surface. The 4-foot depth will be referred to as the surface-following depth since the buoy is required to track the seaway surface contour of swells and waves. The surface-following depth requires a dynamically responsive servo system, whereas the 20-foot depth keeping requires steady-state servo response.

In regard to the 20-foot depth-keeping mode, the Automatic Manual Selector Switch is placed in the AUTOMATIC position. The Pitch Control Switch is set to position 1 and the gain settings at the input of the servo amplifier are adjusted. The servo amplifier inputs consist of the d-c bias signal from the control potentiometer, the two telemetered buoy signals of stabilizer angle and shallow depth, and a buoy pitch-rate signal from a network in the BIAS data control unit. The pitch-rate signal may be considered negligible under steady towing conditions at the 20-foot depth.

As in Mode 2, the stabilizer will remain at a fixed angle if the sum of the four inputs to the servo amplifier equals zero. If the towing speed is lowered, the buoy will tend to rise to the surface; the telemetered depth signal will change as will the summed input signals. As a result, the stabilizer incidence angle will change to a leading-edge-up position and cause the buoy to pitch down and seek the 20-foot depth level.

The buoy depth can be controlled anywhere in the range of 4 to 40 feet by adjustment of the Depth-Set Control. If the Depth-Set Control is adjusted to make the buoy follow 4-feet below the surface, the pitch-rate signal will become a significant input signal to the servo amplifier, particularly in a rough sea. The pitch-rate signal is phased so that any change in buoy pitch will cause the stabilizer to rotate in a direction to oppose the pitch change. For example, if the buoy is being towed 4-feet below the surface and encounters a 2-foot high

swell, the depth sensor will indicate an increasing depth causing the buoy to pitch nose-up. As the buoy starts to pitch nose-up, the pitch-rate signal will limit or slow the rate of buoy climb. When the buoy has passed the crest of the swell it will start to nose down and its rate of descent will also be slowed down by the pitch-rate signal. Some deviation from the desired 4-foot depth mark will be experienced as a result of the pitch-rate input and deviation will increase as the buoy speed of encounter to the swells increases. However, if the buoy is towed in short-crested waves and no pitch-rate feedback is input into the servo amplifier, the buoy should respond to the leading edge of the wave by rapidly nosing up. After the buoy passes the peak it could not respond to the steep trailing edge of a wave and might broach or pass through the water surface. Buoy broaching at high speed is detrimental to the towing system because of the shock to the buoy and shock loads imparted to the towcable. Therefore, the inclusion of the pitch-rate signal in the servo system should serve as a safety feature to the BIAS buoy operation.

BUOY OPERATIONS MEASUREMENT SYSTEM

The Buoy Operations Measurement System was designed to measure only those parameters necessary for operation of the BIAS buoy during operational deployment from the submarine. The parameters are: buoy deep and shallow depth, fine and coarse cable scope, and cable tension. The buoy deep and shallow depth sensors with associated circuitry are mounted in a watertight instrument housing in the buoy. A simplified schematic diagram is presented in Figure 6 and a detailed schematic is shown in DTNSRDC Drawing C-432-5. The shallow depth gage generates a zero to 5-volt d-c output for a depth variation from zero to 50 feet. The deep-depth gage generates a 0- to 5-volt d-c output for a depth variation from 0 to 1000 feet. These two voltages are summed at the amplifier and converted to d-c currents of 5 milliamps (mA) at zero buoy depth, 7.5 mA for 50-foot buoy depth, and a maximum of 10 mA for a buoy depth of 1000 feet. The current signal for depth passes through one lead of the towcable to a grounded 1000-ohm resistor located in the data center. A second amplifier is provided to null out the 5-volt d-c offset at zero buoy depth and to provide proper drive for the buoy-depth meter readout at the data center.

A calibration circuit within the buoy is actuated by a pushbutton switch at the data center to monitor and maintain meter readout accuracy.

SYSTEMS DESCRIPTION

This section describes the buoy measurement instrumentation, electrical conductors, submarine sensors, recording and auxiliary equipment. Two distinct measurement systems and an automatic buoy depth-keeping servo system which were manufactured under the

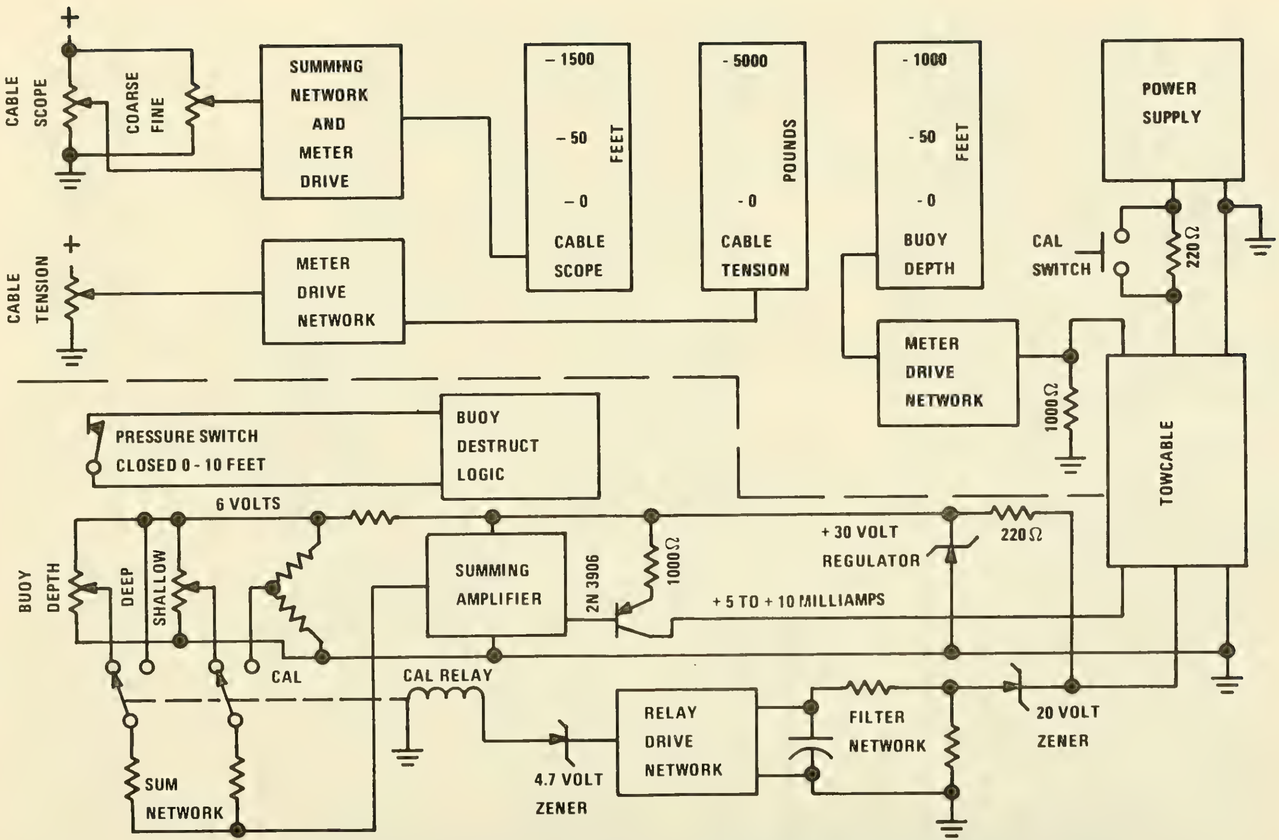

Figure 6 – Partial Schematic of the Buoy Operations Measurement System

BIAS Buoy Program are described. Diagrams of the complete measurement systems are shown in DTNSRDC Drawings C-398 and C-432.

BUOY EVALUATION MEASUREMENT SYSTEM

The measurement system used for BIAS buoy evaluation is divided into four sections to simplify discussion. These are buoy instrumentation, towcable, shipboard sensors, and data center instrumentation.

Buoy Instrumentation

The buoy instrumentation consists of three units located within the buoy housing. One unit is an instrumentation package consisting of the buoy pitch and deep-depth sensors, the remotely-controlled calibration networks, a four-channel FM telemetry transmitter, a d-c voltage regulator, and two leak detector networks. This package is placed in a space in the stern of the buoy normally used to hold the buoy depth instrument housing. The second unit, the stabilizer-angle sensor, is located in the center vertical fin of the buoy and, finally, the shallow-depth gage with associated blanking valve is located in the buoy near the tow-point. The buoy evaluation instrument housing with interconnecting cables to the shallow depth sensor with blanking valve and to the stabilizer servo-motor assembly is shown in Figure 7.

The calibration network consists of a printed circuit board including a relaxation oscillator, sillicone-controlled rectifier, and a 500-micro-farad condenser, and a rotary-solenoid Ledex switch Model S-1009-041, Size 2E. A circuit diagram of the calibration network is included in DTNSRDC Drawing C-432-2.

The four-channel FM telemetry subsystem is made up of four voltage-controlled oscillators (VCO's) and a mixer-amplifier output unit. The VCO's are IED, Division of Conic Corporation, Model CSO-235A, and the mixer-amplifier is IED Model CMA-435A.

The d-c voltage-shunt regulator (Super-reg Model 75T27) supplies 28 volts d-c to all the electronic circuitry in the buoy. Input power to the regulator is supplied via the towcable from a regulated current supply of 135 milliamps located in the data center.

The leak detector consists of a strip of brass positioned near the inside bottom of the instrument housing and is electrically insulated from the housing which is at ground potential. A drop of water in the housing will partially short the strip to ground, which will cause a relaxation oscillator to emit a sawtooth oscillation. Oscillation-signal peaks are detected in the recorded pitch readout and serves as a leak warning signal.

A second leak detector is located in the servo motor cavity of the buoy center vertical fin. A leak signal in this area is detected in the recorded deep-depth readout channel.

Figure 7 – Buoy Evaluation Instrument Housing, Shallow Depth Sensor and Stabilizer Servo-Motor Assembly

Towcable

The towcable, Rochester Corporation 9-H-347, which serves as a mechanical and electrical link between the BIAS buoy and the submarine, is of the double armored type and contains nine insulated conductors. Eight conductors are number 22 AWG and one is number 18 AWG. The cable is 0.347 inch in diameter and has a breaking strength of 9500 pounds. The armor serves as a common ground for all the communication systems, measurement system, and depth-keeping system. Three of the number 22 AWG conductors are designated for use with the measurement system and depth-keeping system. These same three conductors are used for the buoy operational measurement system when installed. The conductors and armor are electrically terminated at the towstaff of the buoy by a twelve-pin Bendix Pigmy male-chassis connector. A special interconnecting-cable harness between the towstaff and all the BIAS buoy electronics was manufactured by Marsh and Marine of the Vector Cable Company. Details of the harness and towcable conductor distributions are shown in DTNSRDC Drawing C-432-3. The ship end of the towcable is terminated in ten each, one conductor Marsh and Marine watertight leads. These leads are connected with mating wires and are directed to a ten conductor slip-ring assembly, Superior Carbon Products, Inc., Model 096103-SCP-8.

The output of the assembly is cabled to a pressure-proof watertight bulkhead connector to bring the conductors from the sea to the submarine interior. After passing through several terminal blocks, three leads and a ground conductor are connected to the control unit of the buoy evaluation measurement system.

Shipboard Sensors

The cable tension strain-gage assembly, manufactured by Oak Ridge, part number 2161, is a 700-ohm strain-gage bridge mounted on a steel flexure with a range of 0 to 10,000 pounds. This sensor is mounted on the towcable winch assembly and is subjected to the seawater and pressure environment. It is directly connected to the data center control unit.

The fine cable-scope sensor is a 300-ohm, single-turn potentiometer (with no mechanical stops), mechanically coupled to the towcable winch-drum shaft. One complete rotation of the potentiometer is equivalent to approximately 75 feet of towcable. The sensor has no mechanical stops so it is capable of sensing repeated 75-foot increments of towcable lengths. This measurement is useful in fine adjustment or inching operations of the buoy towcable.

The coarse cable scope sensor is a 300-ohm, 25-turn potentiometer, mechanically coupled to the towcable winch-drum shaft. This sensor is used for measurement of the overall length of towcable deployed. The fine and coarse scope potentiometers are electrically energized in parallel producing two output signals and requiring only four conductors. These leads are directly cabled to the data center control unit.

The submarine depth sensor is a 2000-ohm potentiometer-type pressure gage. It is designed for a pressure range of 14.7 to 457.7 psia, which is equivalent to a seawater depth range of 0 to 1000 feet. The pressure gage, fitted inside a watertight housing with the pressure orifice open to the sea, is mounted to the cable-winching assembly in the BIAS buoy nest. Leads from this sensor also are direct wired to the data center control unit.

The submarine speed signal is provided from the ship's electromagnetic log via a synchro-potentiometer circuit aboard the submarine.

Data Center Instrumentation

The instrumentation used for obtaining recorded data during buoy evaluation trials consists of six units:

1. A data center control unit of DTNSRDC design.
2. A four-channel frequency-modulated (FM) discriminator unit Defense Electronics, Inc., Model SCD-11.[1]
3. A 6-channel to 3-channel analog multiplexer of DTNSRDC design.
4. A 6-channel strip-chart recorder, Brush Mark 260.[2]
5. A 36-volt d-c, one-ampere power supply, Kepco Model SC-36-1M.[3]
6. A 60-volt d-c, 500-milliampere power supply, Kepco Model CK60-0.5M.[4]

The data center control unit serves as a distribution terminal for system power and data input-output signals. It also contains the signal-conditioning electronics and calibration circuitry for the shipboard sensors and contains the d-c servo amplifier along with signal-conditioning electronics for the amplifier inputs. The switches and potentiometer controls for the depth-keeping system and a pushbutton for measurement calibrations are located on the front panel of this unit.

The FM discriminator unit is used to demodulate the four telemetered buoy sensor signals. Three of the analog output signals (buoy pitch, shallow depth and stabilizer angle) are input to the control unit for use with the depth-keeping servo. These same signals from the discriminator, plus the buoy deep-depth signal also are connected to four input channels of the analog time-sharing multiplexer for ultimate recording on two channels of the strip-chart recorder.

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[1] "Instruction Manual, Model SCD-11 Subcarrier Discriminator," Defense Electronics, Inc., Rockville, Maryland (1970). A complete listing of references is given on page 34.

[2] "Operating Instructions, Mark 260 Recorder," Gould, Inc., Cleveland, Ohio (1971).

[3] "Kepco Instruction Manual, Model SC-36-1M, Voltage Regulated Power Supply," Kepco, Inc., Flushing, New York (1958).

[4] "Instruction Manual, Model CK60-0.5M, Regulated DC Supply," Kepco, Inc., Flushing, New York (1967).

The analog multiplexer provides a method of recording six analog signals (by means of time sharing) on three channels of the recorder. Two signals are fed into one section of the multiplexer, where the signals are alternately switched to a single output line. The time each signal is on line is adjustable from the front panel.

The 6-channel strip-chart recorder provides a time-history ink trace of the nine BIAS buoy measurements (six channels time shared and three channels direct). Each channel of recording is 40-millimeters (mm) wide scaled into 50 units providing a reading resolution of one-half percent of full scale or one-fifth mm. The chart speed is incrementally adjustable from one mm per minute to 125 mm per second.

The 36-volt power supply, adjusted to 30 volts, is used to power the servo motor in manual-mode operation and to power the servo amplifier in the automatic modes of operation of the depth control system.

The 60-volt, 500-milliampere d-c power supply, adjusted for a constant current of 135 milliamperes, provides power to all the measurement electronics in the buoy.

AUTOMATIC DEPTH-KEEPING SYSTEM

The BIAS buoy is fitted with a horizontal stabilizer which is adjustable through a range of incidence angles from 15-degrees leading edge up to 15-degrees leading edge down. A d-c servo motor, Globe Industries, Model 43A152-7, located in the center vertical fin, actuates the horizontal stabilizer through a 10 to 1 worm-gear ratio. A potentiometer which serves as the stabilizer-position sensor is geared to the servo motor output shaft. Two micro switches actuated by a cam mounted on the servo motor shaft limit the stabilizer to plus or minus 15-degrees rotation. The mechanical arrangement of the above equipment is shown on DTNSRDC Drawings E-2773-13, -14, and -16.

The servo motor is electrically driven by a servo amplifier (WESTAMP, Inc., Model A457) located in the data center buoy control unit; interconnection is provided by two leads in the towcable. The servo amplifier is a linear d-c power amplifier with three summing inputs. The three buoy sensor signals of shallow depth, stabilizer position and pitch (which is differentiated to produce pitch rate) are obtained from the output of the discriminator unit in the data control center. The three buoy sensors are described in the Buoy Evaluation Measurement Systems section. These sensor signals plus a manually-controlled depth-selection signal are connected to the inputs of the servo amplifier which drives the servo motor and completes the servo feedback loop. A Philbrick Chopper Stabilized Amplifier Model P656 is used as part of the pitch differentiating circuit.

The d-c servo amplifier is powered by a 28-volt d-c, 1-ampere Kepco Power Supply (Model SC-36-1M) located in the data control center.

BUOY OPERATIONS MEASUREMENT SYSTEM

A second measurement system, which was designed as a permanent part of the BIAS buoy system, is used during submarine patrols. This system utilizes several of the aforementioned shipboard sensors, but requires different buoy instrumentation consisting of a shallow-depth gage (0 to 50 feet) with a blanking valve attached to the pressure orifice to protect from overpressure; a deep-depth gage (0 to 1000 feet); a pressure sensitive switch which is closed between 0 to 10 feet of depth; electronics to sum the shallow- and deep-depth signals; and a watertight instrument housing to contain the above items. The instrument housing is electrically connected to the submarine buoy control center via two leads and a shared ground lead of the towcable. A power supply, signal-conditioning electronics, and a meter are provided aboard the submarine for depth readout. A pressure-sensitive switch is provided as one of several inputs to the logic circuitry for buoy destruction.

The accuracy of this system, assuming a worst case condition over a range of a 20-degree-Fahrenheit temperature change, is determined to be approximately 5 percent of full scale. A 3-percent error is attributed to the sensor, largely due to temperature variation, a 0.5-percent error is attributed to the meter driving electronics, and a 1.5-percent error is due to the nonlinearity and friction within the meter readout unit.

BUOY EVALUATION MEASUREMENT SYSTEM ACCURACY

The accuracy of recorded buoy data obtainable from the evaluation measurement system is essentially limited only by the accuracy of the sensor, the resolution of the readout device, and the requirement of short term zero and sensitivity stability of the telemetry and recording electronics. In general, the accuracy of the potentiometric-type sensors used in this system is primarily affected by the systematic errors caused from environmental temperature variations and the electro-mechanical nonlinearity inherent to each sensor. A temperature change effects both an electrical resistance change and mechanical dimensional change to the linkage within the sensor. Temperature changes affecting the electrical resistance of the sensors do not affect the accuracy of the final data because of the calibration networks designed for use in this system. Each network is comprised of precision resistors connected in series and the total network connected in parallel with the sensor. Each junction between the resistors of the network represents a discrete position of the potentiometer arm and this relationship is independent of temperature because the resistance of the potentiometer changes uniformly throughout the resistance element. The errors caused by dimensional changes due to temperature (particularly in the depth sensors which contain more complicated linkages) do affect final data accuracy.

Secondary random errors affecting sensor accuracy are caused by friction, degree of resolution, potentiometer wiper noise, hysteresis, shock and vibration. The errors due to friction are greatly reduced due to the ever-present vibrations associated with buoy towing.

The potentiometer sensor accuracies shown in Table 1 represent the cumulative systematic and random errors as specified for each type of sensor by the manufacturer. Empirical calibration data taken at DTNSRDC show a combined error of less than 0.5 percent of full scale when a vibrator is used to reduce static friction and air temperature is held constant to within plus or minus 1-degree Fahrenheit, during the calibration.

The cable tension sensor used aboard the submarine consists of a custom made strain-gaged flexure designed as an integral part of the winching system and for this reason calibration of this sensor must be performed aboard the submarine. The strain-gaged flexure is mounted between the winch bearing housing and the winch base so that a tension applied to the towcable must be transferred to the winch drum and the winch bearing housing before being sensed by the flexure. There is a large cable sheave external to the winch over which the towcable must travel during the winching operation. A calibration is performed by placing a calibrated Baldwin-Lima-Hamilton load cell in line with the towcable outboard of the sheave. The cable is incrementally tensioned using a ratchet hoist. The accuracy of the tension sensor was determined to be approximately 5 percent of full scale based on the empirical data of several calibrations, which include the errors due to the static friction of the winch bearings and sheave.

During the buoy evaluation in the towing basin at DTNSRDC, a tension sensor accuracy of 0.5 percent of full scale was realized using a Baldwin-Lima-Hamilton load cell. Towing carriage speed is measured to an accuracy of better than 0.01 knot. The submarine speed sensor, an electromagnetic log, is part of the ship's equipment and its accuracy is unknown.

The calibration network is made up of resistors which are subject to variation as a function of temperature. A variation of temperature would affect an error in output data only if each resistor value did not change proportionately with the remaining resistors. The problem is minimized by using resistors where each is made of the same material and specifying temper ature compensated resistors which vary only 50 parts per million per degree Centigrade. Another component of the calibration circuitry includes a one-pole four-position switch for each sensor. The contact resistance of these switches is specified to be no greater than 0.02 ohm; this resistance is in series with an amplifier input impedance of 10,000 ohms and may be neglected. The overall worst case error introduced by the calibration circuitry is calculated to be less than 0.1 percent of full scale for a temperature variation of 20-degree Fahrenheit.

The telemetry electronics, including the transmitting and receiving unit, have a combined error of 0.3 percent of full scale attributable to nonlinearity. Variations due to temperature will be shown to have no affect on final data accuracy.

The servo-type strip-chart recorder error of nonlinearity is specified as less than 0.5 percent of full scale. Worst case zero shift and sensitivity change due to temperature variation of 20-degrees Fahrenheit is 2.5 percent of full scale. Worst case zero shift and sensitivity change due to line voltage variation is 1.5 percent of full scale for a 10-percent change in line voltage of 115 volts, 60 Hertz. However, both the temperature and voltage variation effects will be shown in the following sections to have no effect on final data accuracy. The readout resolution of the recorder is approximately 0.5 percent of full scale based on a specified ink-trace width of 0.25 millimeter which is 0.5 percent of full scale. During basin tests of the BIAS buoy, digital readout devices with readout resolutions of 0.1 percent of full scale were used in conjunction with the recorder to eliminate the human error of bias and interpretation of the recorded output. However, due to limited space on the submarine only the recorder was allowed as a readout device.

Except for the sensor accuracies, the major contributing factor to overall system error appears to be the nonlinearity of the telemetry electronics and recorder which, when summed (a worst case condition), equal 0.8 percent of full scale. However, a nonlinearity error of this magnitude has not been experienced in any of the calibrations for this system and, furthermore, this is a systematic error for which the final data could be corrected to within the error band of readout resolution.

A remotely-controlled electrical calibration circuit incorporated in the buoy electronics allows for the direct wiring of the sensor to the resistive calibration elements as depicted in Figure 8. As will be shown, when a voltage is applied to this circuit there exists an invariant voltage ratio between the calibration network outputs and the sensor output which is unaffected by external signal-amplifying electronics.

For a clear understanding of the principles involved in this technique the discussion will be limited to the buoy pitch measurement channel which contains a potentiometric-type viscous-damped-pendulum sensor. However, these same principles apply to all the remaining measurement channels in this system. The physical calibration and data reduction procedures are explained and an evaluation of the measurement channel is presented.

CALIBRATION PROCEDURE

The object of calibrating the pitch sensor is to determine the linearity, sensitivity, and hysteresis, and to determine the angle equivalents of the electrical calibration steps in order to establish the ratio between these steps and the sensor output. Physical calibration requires the use of a tilt table with a precision angle scale so the sensor may be rotated through known positive and negative angles where the horizontal plane is defined as zero degrees. The pendulum is affixed to the tilt table and electrically connected to the calibration network, a power supply, and a readout device such as a digital voltmeter (DVM) with a readout resolution and

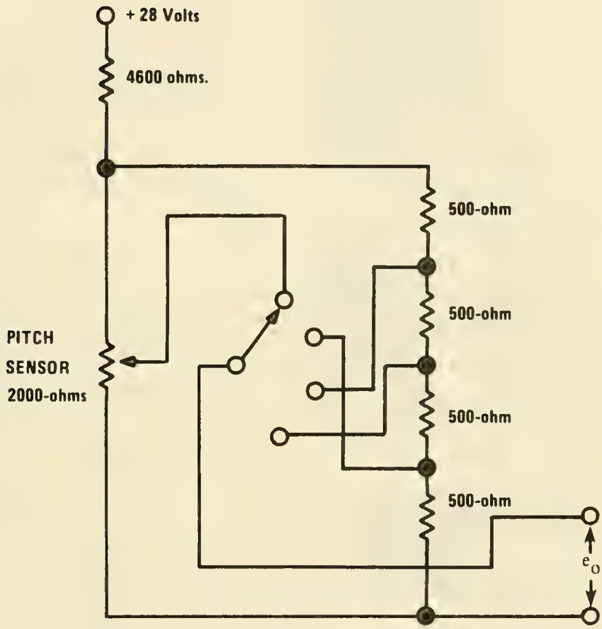


Figure 8 – Schematic of the Electrical-Calibration Network Including the Pitch Sensor

accuracy of at least 0.1 percent of full scale. This arrangement is shown in Figure 9. During calibration of the pendulum sensor a small vibrator is attached to the tilt table to reduce static friction in the bearing; its use is justified because the buoy towing environment is also vibratory. A tabulation of the electrical-calibration sequence (Zero Check, Cal 1, Cal 2, and Data position) from the DVM is made using the electrical calibration network. With the tilt table set at zero degrees, the pendulum sensor is rotated so that the output voltage coincides with the voltage from the zero check calibration step. The zero check voltage is used in referencing the zero degree pitch angle in the data reduction process described later. Once the sensor zero is established, the pendulum is locked in position on the tilt table and a physical calibration is begun. The electrical-calibration sequence is repeated and the resulting voltage outputs tabulated. A tabulation of the sensor output voltage is made while the sensor is incrementally rotated from 0 degrees to minus 20 degrees to plus 20 degrees, and back to 0 degrees. A second electrical-calibration sequence is tabulated. This procedure should be repeated several times to establish repeatability of readings.

To analyze a complete set of calibration data, each known incremental angle and the resulting measured voltage is tabulated and may be plotted on linear graph paper or a least-squares fit may be obtained through use of a computer and the Government Services Administration (GSA) Computer Program available to all government services. The GSA program entitled CURFIT[5] will print out a comparison of a least-squares fit of the calibration data to the equation of a straight line, $y = mX + b$, and will print out the angle in degrees, represented by each of the electrical calibration steps, i.e., Zero Check, Cal 1, and Cal 2. The printout also lists sensor sensitivity (the factor m above), percent deviation from the straight line, and the index of determination where the number 1 represents a perfect curve fit and a number less than 1 indicates the degree of deviation from a straight line. A straight-line curve indicates sensor linearity, the slope of the curve indicates sensor sensitivity, and if the increasing angle curve coincides with the decreasing angle curve, there is no hysteresis. A comparison of the first calibration sequence to the second yields the following information: if the two zero-check points match, there was no instrument zero drift during the calibration; if the differences between the calibration steps ($C_1 - C_2$) in both sequences match, there was no change in excitation voltage or instrumentation sensitivity during the calibration.

The physical zero of the pitch pendulum is again adjusted when the sensor is placed in the buoy. The buoy is positioned to zero degrees pitch and the pendulum is rotated so that its electrical output exactly matches the zero-check voltage from the calibration network.

[5]"Applications Library Operating Instructions," Federal Data Processing Center, Atlanta, Georgia (1973).

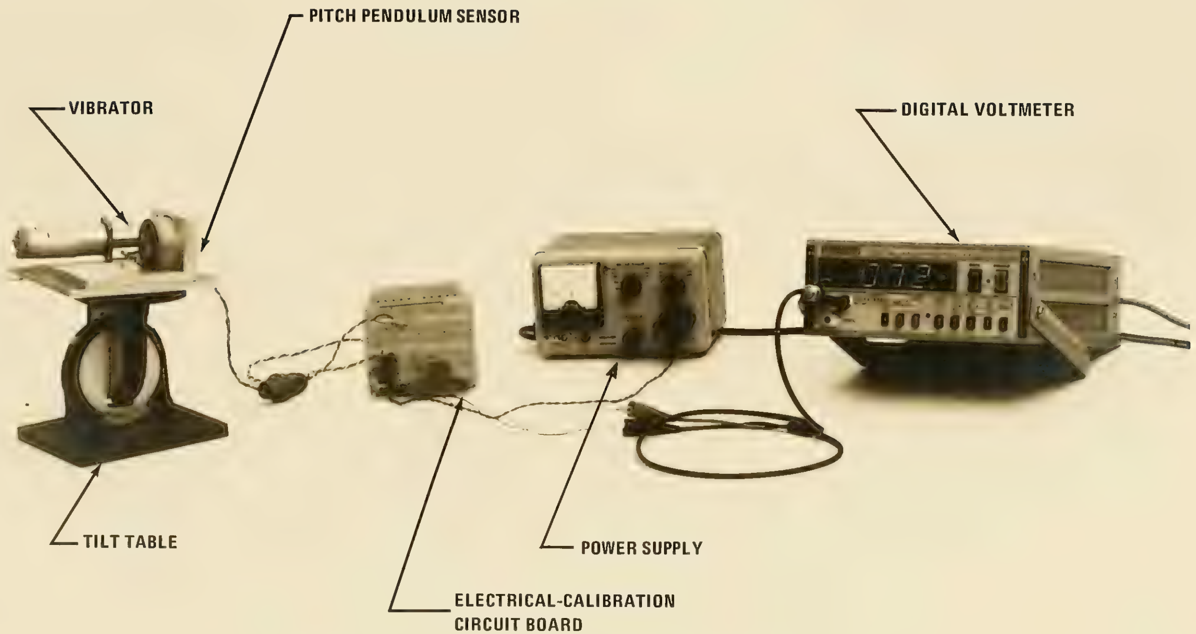


Figure 9 – Pitch Pendulum Calibration Arrangement

When both the zero position and sensitivity calibration have been established for the pitch sensor, no variance can be caused by electrical drift and/or sensitivity change within the instrumentation external to the sensor and electrical calibration network. So long as the datum-point recording, zero check, and calibration steps are within the bounds of the record, a valid datum point is obtained.

The following discussion deals with the relationship between the physical calibration data and the electrical-calibration voltage steps. The type of calibration employed in this system is referred to as a "voltage substitution circuit" where fixed voltages from a resistor divider network are substituted for voltages from the sensor, and each voltage relates to some fixed position or angle of the sensor. A graph of the pitch calibration curve of angular displacement versus voltage output is plotted and presented in Figure 10. The abscissa is a scale of angular displacement, θ, and the ordinate is a scale of sensor output voltage, D. The equation of the physical calibration curve is:

$$D = m_1 \theta + b \tag{1}$$

where D is sensor output voltage

θ is the pitch angle

b is the voltage intercept, where $\theta = 0$

m_1 is the slope of the curve, representing sensor sensitivity

The voltage intercept, b, is the voltage output of the pitch sensor when it is at zero degrees. Furthermore, this same voltage equals the zero check voltage of the calibration sequence, since the sensor was physically rotated at zero degrees so its output and the zero check output would coincide. Therefore, ZC may be substituted for b in Equation (1) which yields

$$D = m_1 \theta + ZC \tag{2}$$

where ZC is the output voltage for $\theta = 0$.

If the voltage values of the calibration sequence (ZC, C_1 and C_2) are plotted on the voltage axis D of the calibration graph, ZC will fall on the curve at the D intercept as mentioned above. If the calibration voltages C_1 and C_2 are projected to the calibration curve at θ_1, C_1 and θ_2, and C_2, the following relationships may be concluded:

$$C_1 = m_2 \theta_1 + ZC$$

$$C_2 = m_2 \theta_2 + ZC$$

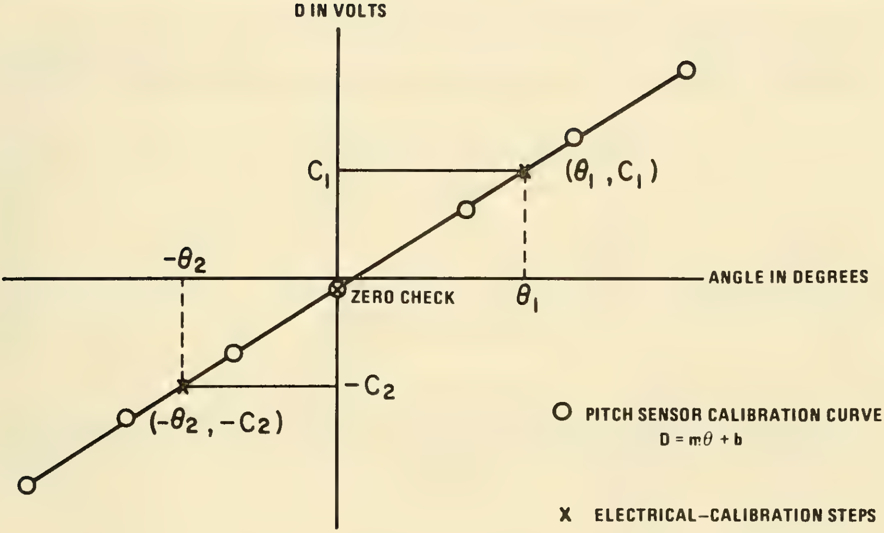


Figure 10 – Pitch-Sensor Calibration Curve with the Electrical-Calibration Steps Superimposed

Taking the difference of the above expressions yields

$$C_1 - C_2 = m_2 (\theta_1 - \theta_2) \tag{3}$$

where C_1 is the positive calibration voltage

C_2 is the negative calibration voltage

θ_1 is the pitch angle represented by C_1

θ_2 is the pitch angle represented by C_2

ZC is the output voltage for $\theta = 0$

m_2 is the slope of electrical-calibration sequence curve

Since the associated curves were made to be identical, $m_1 = m_2$. Therefore, solving for m_1 and m_2 in Equations (2) and (3), respectively, and equating the results yields

$$\frac{D - ZC}{\theta} = \frac{C_1 - C_2}{\theta_1 - \theta_2}$$

or

$$\theta = (\theta_1 - \theta_2) \frac{D - ZC}{C_1 - C_2} \tag{4}$$

Since C_1 and C_2 are fixed voltages, it follows that θ_1 and θ_2 represent fixed angles, and their algebraic difference represents a fixed number of degrees.

Letting $\theta_1 - \theta_2 = K$ yields

$$\theta = \frac{K (D - ZC)}{C_1 - C_2} \tag{5}$$

where K represents a constant number of degrees.

If the physical calibration and electrical-calibration data are computer processed, the value of K in degrees is determined simply by algebraic subtraction of θ_1 and θ_2. To determine the value of K from a graphic calibration curve as in Figure 10, Equation (5) may be used and solving for K

$$K = (C_1 - C_2) \frac{\theta}{D - ZC}$$

where the expression $\frac{\theta}{D - ZC}$ is equal to $\frac{1}{m_1}$ in Equation (2).

Equation (5) was used to reduce the buoy pitch data during basin tests and sea trials on the BIAS system.

DATA REDUCTION PROCEDURE

In the process of data taking, a graphic or digital recording of the electrical-calibration sequence is made before each datum point or group of data points. The frequency of recording the electrical-calibration sequence is a function of the zero and sensitivity stability of the transmitting and recording electronics used in the measurement system. Where a system is highly stable the electrical-calibration sequence may require repeating only once per hour. In fact the stability of the system can be monitored through repeated use of the electrical-calibration sequence where the amount of zero drift or sensitivity drift can be determined. For each electrical-calibration sequence, there will be four readings for each data channel: a zero check, two electrical-calibration steps, and a datum point. The electrical zero-check reading is equivalent to a physical zero at the sensor, and the datum point is a measure of the parameter experienced by the sensor.

Equation (5) is used to reduce the angle data from the buoy pitch and horizontal stabilizer channels. These two parameters require a positive and negative readout with the zero position in the center of the readout scale. Equation (5) is repeated here for convenience:

$$\theta = \frac{K\ (D - ZC)}{C_1 - C_2}$$

In the case of the buoy shallow and deep depth channels, the readout starts from a zero position and increases positively as depth is increased from the water surface. A variation of Equation (5) is used to reduce these data channels.

$$DP = \frac{K\ (D - ZC)}{C_1 - ZC} \qquad (6)$$

where DP is the measure of depth in feet

K is a constant number of feet represented by the voltage $C_1 - ZC$

D is the datum point

ZC is the sensor zero-depth voltage

C_1 is the most positive calibration voltage

In regard to the sensors at the submarine; including submarine depth, fine and coarse cable scope, and cable tension, all require readouts that start from a zero position and increase positively. Therefore, a data reduction equation in the form of Equation (6) is used for reducing data from these channels.

EVALUATION EXPERIMENTS

To evaluate properly the pitch measurement channel, the differences between it and a conventional measurement channel should be understood. In any measurement system, the accuracy of the recorded data is a function of instrument and sensor stability and sensor accuracy. Since no recording system maintains perfect stability, a means of monitoring or eliminating the effect of instrumentation zero and sensitivity shifts is required.

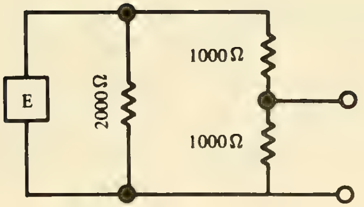
In the evaluation measurement system, the sensor and calibration network are interconnected to form a single unit. A circuit diagram of the electrical calibration network for the potentiometer-type sensor is shown in Figure 8. With a common voltage source supplying input to both the sensor and calibration network, an interrelationship exists between the electrical-calibration readings and the sensor-output signal such that the amplitude of the calibration steps is a direct measure of sensor sensitivity. This arrangement permits physical calibration of a sensor in the early stages of system development, since the sensor with associated calibration network are the only components of the total system required for the physical calibration. Transmitting electronics and other signal conditioning components which will be added to complete a measurement system are not required for this calibration. Even the final readout device for the completed system may be selected or changed at a later date. Two additional advantages of this design over conventional designs are:

1. The accuracy of recorded data is not affected by a long-term variations of sensor-excitation voltage.

2. The accuracy of data is not affected by long-term zero or sensitivity shifts within the signal transmitting electronics or recording instrumentation.

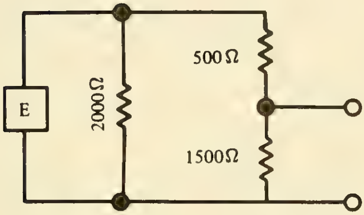
To illustrate that long-term variations in the sensor excitation voltage have no effect on the accuracy of sensor output, typical cases are shown for the pitch measurement channel. The same analyses apply, of course, to other channels using the same resistive-types of sensors.

The schematic diagram in Figure 11 shows the arrangement of the pitch-angle potentiometer and the resistors of the calibration network for the four switch positions previously



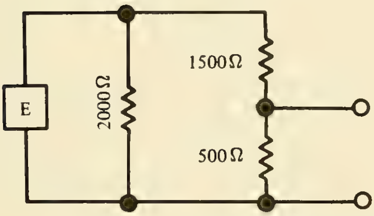
$$e_{o1} = E\,\frac{1000}{2000} = 0.5E$$

Figure 11a - Position 1 (Zero Check, ZC)



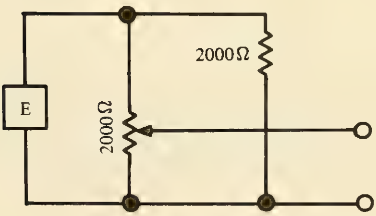
$$e_{o2} = E\,\frac{1500}{2000} = 0.75E$$

Figure 11b - Position 2 (Positive Calibration, C_1)



$$e_{o3} = E\,\frac{500}{2000} = 0.25E$$

Figure 11c - Position 3 (Negative Calibration, C_2)



$$e_{o4} = E\,\frac{2000A}{2000} = EA$$

Figure 11d - Position 4 (Data Output, D)

Figure 11 – Simplified Schematic of the Pitch-Angle Sensor and Calibration Network for Each Switch Position

described. A constant input voltage, E, is provided as excitation to the sensor and calibration network. Assuming that the potentiometer arm is physically located at any arbitrary point on the 2000-ohm potentiometer, the resistance of that portion of the potentiometer between the lower end of the network and the potentiometer arm is 2000-A where $0 \leqslant A \leqslant 1$. The output voltage, e_0, for each switch position is calculated in Figure 11. For these calculations, the external load impedance is neglected since it is greater than 100 times the network output resistance. From Equation (5), the general expression for the pitch angle is

$$\theta = \frac{K\,(D - ZC)}{C_1 - C_2}$$

For the arbitrary points, the pitch angle θ is obtained by substituting the expressions for e_0 shown in Figure 11 into Equation (5) since D, ZC, C_1, and C_2 are all represented by the output voltages from the various switch positions. Thus, the pitch angle

$$\theta = \frac{K\,[EA - 0.5E]}{0.75E - 0.25E}$$

$$= K\,(2A - 1)$$

is independent of long-term variations in the excitation voltage and depends only on the value of K and the position of the potentiometer arm. The only requirement is that the excitation voltage remains constant during the calibration sequence.

To illustrate that long-term zero or sensitivity shifts within the transmitting electronics or the recording instrumentation have no effect on the accuracy of the data, typical cases are shown for the pitch-angle channel. The same analyses apply to other channels using the same resistive-type sensors. In the absence of any zero or sensitivity shifts, the measured pitch angle at a particular towing condition is:

$$\theta_1 = \frac{K\,(D - ZC)}{C_1 - C_2}$$

Assume a zero shift of an arbitrary amount ΔZ. This will shift all points in the calibration sequence and also the datum point by ΔZ. In addition, assume an arbitrary change in sensitivity of X percent, where $-\infty \leqslant X \leqslant +\infty$ but $X \neq 0$. With these assumptions, the measured pitch angle at the same towing condition is:

$$\theta_2 = \frac{K[X(D + \Delta Z) - X(ZC + \Delta Z)]}{X(C_1 + \Delta Z) - X(C_2 + \Delta Z)}$$

$$= \frac{K\ (D - ZC)}{C_1 - C_2}$$

$$= \theta_1$$

Thus the angular measurement is independent of long-term zero and sensitivity shifts in the data transmitting electronics or recording instruments. The only requirement is that the calibration sequence and data points remain within the bounds of the recording scale.

CONCLUSIONS

Based on the results of the development-assist trials on a submarine, the following conclusions are drawn.

1. The BIAS buoy evaluation measurement system adequately furnished all of the recorded measurement parameters required for evaluation of the BIAS buoy system. These parameters included: buoy pitch, horizontal stabilizer angle, depth (shallow and deep), cable tension at the submarine, cable scope (fine and coarse), submarine depth, and speed. The overall accuracy of measurement was approximately one percent of full scale, except for cable tension which was approximately 5 percent, or essentially that of the individual sensors involved.

2. The automatic depth-keeping system, used in conjunction with the above measurement system, showed little if any improvement over the inherent surface following characteristics of the buoy. At the deeper depths (20 feet) an improvement in long-term towing was realized wherein the automatic depth-keeping servo would hold the buoy at a constant depth even though the submarine speed or depth varied somewhat. However, a greater cable scope would be required to compensate for increased speed or increased deviations of submarine depth.

3. The buoy operational measurement system provides all of the measurement parameters necessary for operation of the BIAS buoy system while on patrol. The measurement parameters, displayed as meter readouts, include: buoy deep and shallow depth, fine and coarse cable scope, and cable tension. The overall accuracy of this system was determined to be approximately 5 percent of full scale.

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